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IN THE WESTERN US

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SMELTERS IN THE WESTERN US

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The body of information presented is directed to environmental scientists and policy makers without chemical or metallurgical engineering backgrounds. This paper addresses the problems of reducing sulfur dioxide emissions from primary copper smelters in the western United States and projects the future impact of emissions within a framework of legal, technological, and economic considerations. Methodology used to calculate historical sulfur dioxide emissions is described. Sulfur dioxide emission regulations are outlined as they apply to primary copper smelters. A discussion of available sulfur dioxide control technology and copper smelting processes summarizes the technological and economic problems of reducing copper smelter emissions. Based upon these technological and economic considerations, projections of smelter emissions indicate that compliance with existing legislative requirements will be achieved by 1990. Three smelters are projected to close by 1985.

Introduction

The US Environmental Protection Agency has estimated that in 1970, 34 million tons of sulfur dioxide were introduced into the atmosphere by US sources. Although the greatest source of sulfur dioxide emissions was coal-fired electric power generation, primary copper smelters emitted about 10.6% of the total for that year. In addition, the impact of smelter emissions is greater in the western half of the country where most of the US primary smelters are located (see Table I).

Emissions Trend

We calculated historical sulfur dioxide emissions from copper smelters in the western US to illustrate recent trends. Our calculations were based upon published emissions inventories, when available, and upon metal production data, sulfur balance data, rated smelter capacities and sulfur dioxide control. With the enactment of federal and state clean air legislation, state air pollution control agencies have required emission data from major sources, including primary copper smelters, and have maintained records of air quality measurements. The public records can be used to determine the magnitude of smelter emissions for recent years. Unfortunately, emissions inventories in most states are available only for the past five to ten years. However, emissions for earlier years can be calculated from metal production data provided that the sulfur content of the ore and the level of sulfur dioxide control installed at a smelter are known. In 1974, the A.D. Little Company reported average sulfur content in copper concentrates at all of the smelters included in this study. To use these figures to calculate earlier emissions, we made several assumptions described below.

Most of the smelters received concentrated ores from the same mines over the years 1965-75. However, several smelters received varying amounts of concentrates from different sources. We assumed that the overall average sulfur content of these concentrates did not change significantly. In addition, we assumed no change in the efficiency of the process employed to remove other sulfur containing minerals from copper sulfide minerals in the ore. Variations in the amount of iron sulfides, in particular, would affect the amount of sulfur dioxide produced during smelting.

We assembled data on sulfur dioxide control from several sources. In some cases, where the overall sulfur capture was not reported, we estimated the level of control from the type of air pollution control technology and the plant configuration. We did not attempt to distinguish between stack emissions and fugitive emissions in our estimates. Because our sulfur dioxide emission estimates are based upon the tonnage of copper metal produced, we did not consider the approximately two percent input sulfur captured in the slag as contributing to overall sulfur dioxide control. This 2% is approximately equal to that associated with the unrecovered copper.

Our calculations of sulfur dioxide emissions from western copper smelters for the years 1965-1975 are presented in Table II. With the

TABLE I. Domestic primary copper smelters currently in operation.

Smelter	Location	Years of Initial Operation	Process		
			Roasters	Furnace	Converters
ASARCO, Inc.	El Paso, Texas	1905	Multiple Hearth	Reverb	Pierce-Smith
	Hayden, Arizona	1912	Multiple Hearth	Reverb	Pierce-Smith
	Tacoma, Washington	1890	Multiple Hearth	Reverb	Pierce-Smith
Anaconda	Anaconda, Montana	1906	Fluid Bed	Electric	Pierce-Smith
Cities Service, Co.	Copperhill, Tennessee	1845	Fluid Bed	Electric	Pierce-Smith
Inspiration Consolidated	Miami, Arizona	1915	-	Electric	Hoboken
Kennecott Copper Co.	Garfield, Utah	1907	-	Noranda	-
	Hayden, Arizona	1958	Fluid Bed	Reverb	Pierce-Smith
	Murley, New Mexico	1939	-	Reverb	Pierce-Smith
	McGill, Nevada	1907	-	Reverb	Pierce-Smith
Magma Copper Co.	San Manuel, Arizona	1936	-	Reverb	Pierce-Smith
Phelps Dodge Corp.	Ajo, Arizona	1950	-	Reverb	Pierce-Smith
	Douglas, Arizona	1910	Multiple Hearth	Reverb	Pierce-Smith
	Morenci, Arizona	1942	Fluid Bed	Reverb (2) Greenfeed	Pierce-Smith
	Playas, New Mexico	1976	-	Reverb (3) Flash	Pierce-Smith
White Pine Copper Co.	White Pine, Michigan	1955	-	Reverb	Pierce-Smith

TABLE II. Calculated Sulfur dioxide emissions from primary copper smelters in the West 1965-1975, (Kilotons/yr).

State	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Arizona	1615	1734	994	1108	1700	1869	1745	2059	2242	1825	1188
Montana	341	377	192	263	370	413	326	713	314	318	262
New Mexico	198	228	135	206	208	174	154	159	148	117	46
Nevada	98	107	64	81	118	121	116	113	144	110	61
Texas	174	215	119	192	219	201	171	17	205	40	45
Utah	334	352	267	344	437	436	378	336	327	273	154
Washington	201	203	116	141	186	205	182	202	199	121	100
Total	2961	3216	1887	2325	3238	3418	3072	3460	3179	2804	2036

exception of the major strike in 1967 and a lesser strike in 1971, decreases in emissions can be attributed to emissions reduction efforts by the smelters.

Regulatory Considerations

To project future emissions, we have examined regulatory, technological and economic considerations. Based upon historical evidence, the most important factor in determining the magnitude of sulfur dioxide emissions is the regulatory environment. After a brief description of federal and state legislation and of the issues that have arisen, we will describe technological and economic difficulties in complying with clean air legislation.

The present regulation of atmospheric pollution produced by nonferrous smelters derives from the 1967 Clean Air Act and its Amendments of 1970 and 1977, in which Congress established a national legislative framework designed to protect air quality.

In 1971, the EPA promulgated National Ambient Air Quality Standards (NAAQS) for six criteria pollutants including sulfur dioxide. Section 110 of the 1970 Clean Air Act Amendments requires states to submit a State Implementation Plan (SIP) designed to improve the air quality in areas already in violation of NAAQS (nonattainment areas) and to maintain these standards throughout the state. State ambient air quality standards adopted in the SIP must be at least as strict as NAAQS. Strategies to reduce emissions from stationary sources, including copper smelters located in nonattainment areas, are included in the SIP. The ultimate emission limitations must be designed to maintain NAAQS regardless of the costs or technological feasibility. Smelters have reduced NAAQS violations by building tall stacks, and by using supplementary control systems that curtail production when meteorological conditions would interfere with the normal dispersion of emissions. However, the 1977 Clean Air Act Amendments specify that emission limitations must reduce the overall atmospheric pollution loading on a continuous basis; dispersion techniques cannot be substituted for continuous emission reduction technology to achieve NAAQS. Compliance with the ultimate emission limitation may be postponed until January 1, 1983, or possibly until January 1, 1988, through the Nonferrous Smelter Order (NSO) program. Nonferrous smelters unable to comply with the permanent emission reduction requirement, either for technical or economic reasons, may continue to use dispersion techniques under an NSO granted by the EPA. During the interim, NAAQS must nevertheless be maintained and research efforts to develop appropriate emission control technology must be undertaken.

In states where the copper smelting industry constitutes a large segment of the economy, emission regulations have become a sensitive political issue. Environmentalists and industry disagree on the economic feasibility of complying with the ultimate emission limitations, which for most smelters require approximately 90% control of sulfur dioxide. The appropriate methodology used to determine acceptable emission limits also is disputed. In several states, these issues are currently being litigated. Sulfur emission limitations adopted by states to control nonferrous smelters have been submitted for EPA approval, although in most cases this approval is still forthcoming. Incompatibilities between state and federal requirements have not yet been resolved and thus, the ultimate level of air pollution control to be required remains in dispute. Until the issues are resolved and SIP emission limits are approved by EPA, smelters must comply with the existing state regulations.

New major stationary sources, including primary nonferrous smelters, must comply with New Source Performance Standards (NSPS) defined by EPA under provisions of the Clean Air Act Amendments. Modified or reconstructed sources whose emissions would exceed those of the old source must also comply with NSPS. These standards in effect require all stack gas streams and fugitive emissions to be controlled by 99% removal of sulfur dioxide.

In addition to NSPS, new major sources must comply with Prevention of Significant Deterioration (PSD) regulations established under Secs. 160-169 of the amended Clean Air Act. PSD regulations are intended to protect areas in which ambient air is cleaner than required to meet NAAQS and will limit the number of sites available for construction of a new

("grassroots") smelter. New facilities must demonstrate that the projected emissions will not exceed PSD increments or violate NAAQS, and that the best available control technology will be applied.

Technological Considerations

For certain smelters in this study, there are technological and economic difficulties in complying with the current regulations. These difficulties are associated with reducing sulfur dioxide emissions from reverberatory furnaces (reverbs), operated by ten of the fourteen smelters in the western US. Pollution control technology has not been installed at any of these reverbs. Electric furnaces, flash furnaces, and continuous smelting processes are new and more efficient types of systems for smelting copper. Among the advantages offered by the newer technologies are reduced operating costs, reduced fugitive emissions, more easily controlled process emissions, and more streamlined materials handling. However, replacement of reverbs requires an enormous capital investment, an alternative that companies must weigh against the costs of retrofitting reverberatory furnaces to comply with strict emissions regulations.

The problems of reducing sulfur dioxide emissions from reverbs can best be described within the context of the entire smelting process. The copper containing ores smelted in the US are primarily sulfide ores, the most abundant being chalcopyrite. The low copper content of the ore, typically less than 1%, is increased before smelting by a concentration process that selectively recovers metal containing particles from the matrix rock. Copper concentrates typically contain 18-.8% copper, 23-33% iron, 23-38% sulfur, varying amounts of silica, magnesium, calcium, and aluminum, and trace amounts of arsenic, lead, zinc, nickel, and other metals.

About half of the US copper smelters roast the dried concentrates before smelting. During roasting, volatile metal impurities escape and a portion of the sulfur is oxidized and released as sulfur dioxide, (see Table III). Roasting reduces the water content and thus improves smelting efficiency, increases the capacity of the furnace, and lowers its operating cost. In the smelting furnace, the concentrates are melted to separate the copper containing layer (matte) from the slag. Some impurities, including sulfur, are oxidized and escape with the furnace offgases. The molten copper matte is transferred to the converters and there undergoes a series of exothermic chemical reactions that ultimately remove the remaining sulfur, iron, and other metal impurities to produce 97-99% pure blister copper containing less than 0.1% sulfur. Fire refining removes the remaining sulfur and yields a copper product that may be marketed or sent to an electrolytic refinery for removal of trace metals.

TABLE III. Average sulfur distribution in traditional copper smelting processes.

Source	Calcine Smelting	Greenfeed Smelting
Roaster	20%	-
Reverberatory furnace	25%	40%
Converter	50%	55%
Slag and Fugitives	0.5%	0.5%

SOURCE: Reference 1.

Pollution Control Technology

The most widely employed technology for controlling sulfur dioxide emissions from copper smelters is the contact sulfuric acid plant. All but two smelters in this study have installed at least one acid plant to control converter gas streams. The gas stream is passed through a series of catalyst beds where most of the sulfur dioxide is catalytically oxidized to sulfur trioxide. The gas stream is then passed into an absorption tower containing 98% sulfuric acid and 2% water; there the sulfur trioxide reacts with water to produce 100% sulfuric acid. The efficiency of sulfur dioxide conversion is increased from 97-98% in a single contact plant to 99% in a double contact plant by returning the gas stream to the acid plant converters after the first pass through the absorption tower. It should be noted that these efficiencies are based on the amount of sulfur in the gas stream treated by the acid plant, not the total amount of sulfur dioxide produced at the smelter. The tailgas containing unreacted sulfur dioxide and unabsorbed sulfur trioxide is usually treated to remove acid mist and then vented to the atmosphere. The product acid may be marketed directly, neutralized for disposal, or used to leach metal from oxide ores.

Several process requirements have a direct bearing upon economic acid plant operation. The gas stream entering the acid plant must be cleaned and dried. During the catalytic oxidation step, it is very important to maintain the gas temperature at 425-455° C. If the concentration of sulfur dioxide in the process gas stream is less than about 4%, supplementary heat must be provided. The size of the catalyst bed is directly proportional to the volumetric flow of gas. Large volumes of offgases, therefore, require large acid plants that are more expensive to operate than acid plants treating concentrated gas streams of small volume.

The concentration of sulfur dioxide in the offgas stream from reverbs is too low to be controlled directly and economically by acid plants because the gas stream requires supplemental heating for the catalytic oxidation step. At this time, none of the gases exhausted from copper converters and roasters can be controlled efficiently. Exhaust gases from the newer smelting processes such as Noranda, Mitsubishi, and flash smelting also are very suitable for control in acid plants, as shown in Table IV.

TABLE IV. Sulfur dioxide concentration in process offgases.

Processes	Average SO ₂ Concentration
Multiple Hearth Roasters	5-10%
Fluid Bed Roasters	12-14%
Flash Roaster	9-10%
Pierce-Smith Converter (tightly hooded)	6-9%
Noboken Converter	9%
Reverberatory Furnace	0.5-2.5%
Electric Furnace	7-10%
Flash Furnace (Outokumpu Oy)	11-14%
Mitsubishi	10%
Noranda	10-20%
Kennecott System at Garfield, Utah	8%

SOURCES: References 2, 3, 4, and 5.

The elemental sulfur plant is another type of air pollution control technology that produces a marketable by-product. Although elemental sulfur plants have been commercially available from Allied Chemical in the US and from Outokumpu Oy in Finland since the early 70s, there are limitations to this process that make it uneconomical for many smelters to install and operate. For the process to work efficiently, particulates must be removed from the gas stream and the reaction temperature must be carefully maintained. The temperature is affected by the ratio of sulfur dioxide to oxygen in the gas stream and by the concentration of sulfur dioxide. Consequently, the only offgas streams from smelter processes that may be controlled economically by elemental sulfur plants and without preconcentration are those discharged from fluid bed roasters (12-14% sulfur dioxide, 1-3% oxygen) and flash smelting furnaces (10-14% sulfur dioxide, 1-3% oxygen). For the elemental sulfur technologies to be applied to a weak offgas stream such as the gas from a reverberatory furnace, the sulfur dioxide would have to be preconcentrated, thereby increasing both capital and operating costs. An elemental sulfur plant has not been operated on a commercial scale by a smelter in this study.

The US Bureau of Mines has developed a modified sulfur reduction system, which has been demonstrated at pilot plants at the Bunker Hill lead smelter in Idaho and at the Magma Copper Company smelter in Arizona. The advantage of this system is that it can control sulfur dioxide at the very low concentrations typical of reverb offgas streams with greater than 90% efficiency. However, the cost of natural gas required by this process amounts to more than one-fourth of the annual operating costs.⁶ The process has thus far been considered by the industry to be an unaffordable alternative, and no commercial scale plants have been built.

Dimethylaniline (DMA) scrubbing and the Wellman-Lord process are technologies that separate and concentrate sulfur dioxide from weak gas streams, making a process gas stream more suitable for treatment in acid plants or elemental sulfur plants. These processes also may be used to desulfurize tailgases from other control processes. The advantage of DMA scrubbing is its efficiency over a large range of sulfur dioxide concentrations (from 3-10%), and it has been operated by ASARCO at the Tacoma smelter since 1974. Although the Wellman-Lord process has not been introduced at any smelter in this study, it is attractive for its simplicity and SO₂ recovery of greater than 90% from power plant gas streams containing less than 1% SO₂. For copper smelters, however, either system is an additional control and its costs, both capital and operating, are added to the costs of other sulfur dioxide control equipment. Energy costs are large in these systems, comprising up to 50% of the total operating cost. DMA scrubbing has an additional disadvantage in that the toxicity of the DMA itself makes containment quite critical.

Weak concentrations of sulfur dioxide in gas streams may be scrubbed by nonregenerative processes. There are several systems that have been developed, all of which capture sulfur dioxide as a salt precipitated from the scrubbing liquor. The scrubbing liquor may be regenerated but the captured sulfur is either marketed or thrown away. Disposal of unmarketable sludge (3-4 lbs sludge/lb SO₂) is a major disadvantage of lime/limestone and double alkali scrubbing systems. Although these systems have not been installed at any US reverb smelter, lime scrubbing

has been introduced at the Onahama reverb smelter in Japan. The by-product gypsum is marketed.

Environmental and economic problems currently face developers of ammonium bisulfite (ABS) scrubbing. Efficiency of the process must be maximized to reduce the loss of unreacted ammonia to the atmosphere as a visible plume. While the ABS scrubbing process achieves high recoveries of sulfur dioxide from weak offgas streams, commercial scale operations depend upon the economic use of recovered ammonium sulfate. Although pilot plant studies have tested these processes, not has been introduced on a commercial scale by a smelter in this study.

Pyrometallurgical Technology

The major problem involved in reducing sulfur dioxide emissions from reverberatory furnaces is the need to treat tremendous volumes of offgases that contain very low concentrations of sulfur dioxide. Reverbs heat the concentrates by means of burners at one end of the furnace. These burners are fueled by natural gas, pulverized coal or oil and require large volumes of air for proper combustion. The enormous volume of gases in the furnace dilutes the sulfur dioxide produced by smelting to concentrations of less than 2% by volume. Although scrubbers can efficiently remove sulfur dioxide at such concentrations (see Table V), operating costs of scrubbing the high volume reverb offgases makes them unattractive alternatives.

Some plant modifications can be made to treat reverb offgases in acid plants already introduced to reduce sulfur dioxide emissions from converters. The addition of fluidized bed roasting can reduce the proportion of sulfur dioxide produced in the furnace. Control of roaster and converter emissions can recover up to 70% of the sulfur in the concentrates. A portion of the furnace offgas may be blended with the roaster emissions to produce a gas stream containing over 4% SO_2 that can be sent to an acid plant for treatment. The overall sulfur capture can be raised to about 80%. Oxygen enrichment of the combustion air in the reverb can effectively increase the concentration of SO_2 in the furnace offgases to make them suitable for acid plant treatment. It has been estimated that fluidized bed roasting, oxygen enrichment, and tightly hooded converters could deliver 85-90% of the feed sulfur to the acid plant at suitable strength.⁸ It should be emphasized that modifications such as described above would require substantial expansion of existing acid plant capacity.

TABLE V. Efficiencies of sulfur dioxide control technologies.

Process	Efficiency ^a	Concentration of SO_2 Treated
Single Contact Sulfuric Acid Plant	97-98%	4-9%
Double Contact Sulfuric Acid Plant	99%	4-9%
Elemental Sulfur Plant	90-95%	12%
DMA Liquid SO_2	95%	4-8%
US Bureau of Mines Citrate Process	95%	1%
Wellman-Lord Process	97%	1%
Lime/Limestone Scrubbing	90%	1%
Double Alkali Processes	97%	1%
ABS Scrubbing	97%	1%

^aEfficiency rating based on removal of sulfur from the gas stream characterized in Column 3.

SOURCES: References 4, 6 and 7.

Extensive modifications at the Onahama reverb smelter in Japan have achieved approximately 99% control of SO_2 . Converter gases are treated in a double contact sulfuric acid plant. Reverb SO_2 emissions are preconcentrated by magnesium oxide scrubbing for treatment in a remodeled sulfuric acid plant. In addition, combustion air is oxygen enriched, air infiltration into the furnace offgas has been effectively controlled, and acid plant tailgases are scrubbed.

Rather than modify existing smelting processes to improve sulfur dioxide control, several smelters in this study have introduced new smelting processes. Kennecott Copper Corporation replaced the reverberatory furnaces at the Garfield smelter with a modified Noranda system. Reverberatory furnaces operated by Anaconda and Inspiration were replaced by electric furnaces. Phelps Dodge elected to build a flash furnace at their new Playas, New Mexico, facility. The principal advantages offered by these newer technologies are reduced operating costs and more economically controlled process emissions than obtainable from a retrofitted reverb smelter.

The characteristics of electric furnace smelting are similar to those of the reverb. Whereas thermal energy from fossil fuel combustion is used in reverbs to melt concentrates, electrical resistance heating is used in electric furnaces. Roasted concentrates and fluxes are distributed on the bath surface and melted by heat generated as an electric current is passed through the slag layer. Convective currents allow the molten layers to separate, the copper matte layer settling to the bottom where it is tapped and transferred to converters. Electric furnaces remove about the same percentage of sulfur from the concentrates as do reverbs. However, the sulfur dioxide produced is not diluted by the large volume of combustion gases typical of reverbs. The 7-10% concentration of sulfur dioxide in electric furnace offgas is suitable for treatment in sulfuric acid plants or elemental sulfur plants. Efficient sulfur recovery, minimal particulate emissions, and lower heat losses make electric furnaces attractive, particularly where favorable contracts for electric power can be obtained.

More energy efficient than either reverbs or electric furnaces are flash furnaces, in which heat for smelting is derived from exothermic chemical reactions produced in the concentrates. Two different processes have been developed, one by the International Nickel Company (Inco) of Canada and the other by Outokumpu Oy of Finland. The Outokumpu process was installed at the Phelps Dodge smelter at Playas, New Mexico. Although roasting is not necessary for flash smelting, concentrates must be dry (less than 0.1% moisture) when they are introduced into the vertical section of the furnace. As the particles fall to the surface of the molten bath, they are ignited by a stream of preheated air (Outokumpu process) or oxygen rich (Inco process) air. Oxidation reactions of iron and sulfur contained in the concentrates produce enough heat to melt the particles. Because the process gas volume is relatively low, sulfur dioxide concentrations in the offgases range from 11-14% in the Outokumpu process and 75-80% in the Inco process. Such high concentrations and low process gas volumes can be treated efficiently and economically in acid or elemental sulfur plants. One of the disadvantages of both types of flash smelters is the need to recover copper from the furnace slag, which contains more than 1% copper by weight.

Other smelting processes designed by Mitsubishi Metal Corporation of Japan and Noranda Mines Ltd. of Canada reduce copper sulfide concentrates directly to blister copper in one continuous operation. Both processes take advantage of the heat producing chemical reactions in the smelting process and thereby reduce fuel consumption. The energy requirements are similar to those of flash smelting. Continuous smelting, however, is not appropriate for dirty concentrates because such a system is unable to reduce the level of metallic contaminants as well as can be done in a separate conversion process.

In the Mitsubishi system, the molten material passes through a series of three specialized furnaces. Since the composition of the concentrates, the materials balance, and the flow must be very carefully managed, the Mitsubishi system may not be an appropriate substitute for the more flexible reverberatory furnace smelting in the US. However, this process is being installed at the Timmins, Ontario, operations of Texasgulf, Canada, and is expected to begin production in 1980. From the standpoint of sulfur dioxide control, the system is very attractive--a continuous low volume stream of about 10% sulfur dioxide is emitted from each furnace.

The Noranda process produces molten slag, matte, and blister copper in one smelting vessel, thereby minimizing material handling, fuel consumption, and capital investment costs. As in the Mitsubishi system, concentrates and flux are introduced continuously. The gas stream emitted from a Noranda reactor contains from 10-20% sulfur dioxide and may be efficiently and economically treated by acid plants or sulfur recovery plants. The fuel consumption is approximately the same as in flash smelting. However, the slag contains 9-12% copper and must be reprocessed to recover the copper. Furthermore, the blister copper contains 1-2% sulfur and may contain a greater concentration of other impurities than blister produced by other smelting systems. Some concentrates are not suitable for smelting with this process because of their high impurity content.⁹

Kennecott Copper Corporation (KCC) has adapted the Noranda system to their Garfield, Utah, operations to reduce operating costs and sulfur dioxide emissions. Matte containing 70-75% copper is produced by 3 modified Noranda reactors; the matte is then treated in converters to remove the remaining impurities. The KCC system produces a strong gas stream averaging 8% sulfur dioxide that is controlled by acid plants to provide an overall sulfur recovery of 86%.

A summary of the technological alternatives to reduce sulfur dioxide emissions is presented in Table VI. Costs of proposed technologies are estimates for installation of new facilities. Until operating data are obtained from large-scale plants, the firm design information concerning corrosion, material handling problems, and process control cannot be determined.

Economic Considerations

The projection of future copper production must take into account certain economic factors, among which are industrial structure and the international market.

Vertically integrated corporations are able to absorb a high cost processing step if they are able to reduce costs elsewhere. Capital spent to increase the efficiency of the mine and concentrator, for example, allow higher smelting and refining costs to be tolerated. Nonintegrated corporations, on the other hand, must pay a fixed charge for smelting and refining. If these charges are increased, profits from the independent operations are reduced. The custom, or toll, smelter passes on the increased costs of smelting to mines that supply the smelter, thereby assuming a risk that the independent miners will ship concentrates abroad for smelting.

Although there is little competition between smelters within the US, there is increasing competition from foreign smelters. From 1964 to 1974, US copper smelter capacity decreased from 26% to 18% of the world capacity. This declining trend is likely to continue. New foreign operations are brought on stream with the best new technology, and fewer occupational safety and environmental protection regulations in Third World countries result in lower smelting costs.¹³

To predict domestic primary copper production, we examined the forecasts of the US Bureau of Mines, the A.D. Little Company, and the US Department of Commerce and compared these forecasts to recent trends in domestic mine production. Since 1975, mine production has not followed

TABLE VI. Process alternatives for copper smelting.

Process Description	Approximate Sulfur Content	Capital Cost (1975 \$/Ton Installed Capacity)	Operating Cost (1975 \$/Ton Produced)	Zinc Use (Million Btu/Ton Produced)
1. Reverb-Converter	0	625	175	18.3
2. Reverb-Converter with acid plant on converters				
a. single contact acid plant	53%	700	186	19.6
b. double contact acid plant	53%	710	188	19.8
3. Roaster-Reverb-Converter with double contact acid plant on strong gases	70%	750	192	17.5
4. Reverb-Converter with single contact acid plant on converters and scrubber on reverb gases	90%			
a. ABS Acidulation		940	282	36.9
b. NH ₃ - Double Alkali		870	264	26.9
c. Sodium - Double Alkali		880	272	26.9
d. Wellman-Lord		930	285	44.5
e. BOM Citrate		880	270	32.1
5. Roaster-Reverb-Converter with Acid Plant (as in # 3) with NH ₃ - Double Alkali scrubber on reverb	92%	855	242	22.1
6. Flash Furnace-Converter with Double Contact Acid Plant	92%	750	258	16.2
7. Noranda-Converter with Acid Plants	87%	750	270	19.1
8. Electric-Converter with Acid Plants	90%	750	300	24.2
9. Mitsubishi Continuous with Acid Plant	93%	750	260	14.0

*The estimated capital costs are no better than 10%.

bIncludes taxes and insurance at 2% of capital, depreciation at 10% of capital, and capital recovery at 10% of capital all on a yearly basis.

SOURCES: References 1, 9, 10, 11 and 12.

projections. In addition, no plans have been announced to expand smelter capacity and few companies have announced capital expenditures. This trend and the environmental difficulties associated with reverbs led us to predict domestic primary copper production will increase to 2 020 000 tons/yr by the year 2000, an increase of 660 000 tons/yr over 1975 production.¹⁴

Projection of Sulfur Dioxide Emissions

Production levels and the choice of appropriate control technology for any smelter depend upon the unique characteristics of the concentrates smelted, the type and age of equipment, and the economic health of the company. For each smelter in this study we estimated copper production and sulfur dioxide emissions, taking into account the regulatory, technological, and economic factors described above, and we made the same assumptions regarding concentrate sulfur content and efficiency of pollution control technology outlined earlier. Copper production and sulfur dioxide emission estimates are summarized by state in Table VII.

We have predicted that the Kennecott McGill smelter in Nevada, the Phelps Dodge smelter at Douglas, Arizona, and the ASARCO smelter near Tacoma, Washington, will close by 1985. The Kennecott and Phelps Dodge smelters are presently operating without control technology and the nearby mines that have supplied these smelters are now closed. Problems with arsenic contamination at the Tacoma smelter will probably shut down this toll smelter within five years.

Conclusions

The smelting industry faces some problems in complying with air pollution control regulations. The costs of introducing new technology or of modifying older processes requires large capital investments that are not readily financible and are not easily absorbed by the smelter. Toll smelters, in particular, cannot remain competitive if they must pass on increased production costs to their clients. However, new metallurgical processes can be more economically controlled by available air pollution control technology and afford greater energy efficiency than traditional processes.

The level of control necessary to protect air quality is disputed. There are currently unresolved disagreements between EPA and state agencies, between EPA and industry, and between state agencies and industry. Issues have arisen in the choice of methodology for determining

TABLE VII. Projections of smelter SO₂ emissions (Kilotons/Yr)

	1985	1990	2000
Copper			
Arizona	537	216	184
Arizona (new smelter)			3
Montana	100	50	55
Nevada	0	0	0
New Mexico	80	57	58
Texas	21	24	24
Utah	57	51	60
Washington	0	0	0
Total	921	398	384

emission limits, in appropriate dispersion modeling to account for local meteorological conditions and terrain features, and in the determination of economic feasibility. The resolution of these and other issues may not be achieved for several years and perhaps then only through litigation in federal courts.

We have projected some delays in scheduled attainment strategies through variances, litigation, or lead-time required for construction of new facilities. We have also concluded that problems would be insuperable for several smelters and that they will cease operating by 1985. While it is difficult to make any long-range forecasts with any certainty, we have estimated that the technological improvements will be developed and introduced at smelters and that levels of control presently required will be installed by 1990.

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